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A Graphical Weather System Design for the NASA Transport Systems Research Vehicle B-737

Charles H. Scanlon

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(NASA-TM-104205) A GRAPHICAL WEATHER SYSTEM
DESIGN FOR THE NASA TRANSPORT SYSTEMS
RESEARCH VEHICLE B-737 (NASA) 19 pCSCL 01D

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

A Graphical Weather System Design for the NASA Transport Systems Research Vehicle B-737

Summary

A graphical weather system has been designed for testing in the NASA Transport Systems Research Vehicle B-737 airplane and simulator. The purpose of these tests is to measure the impact of graphical weather products on aircrew decision processes, weather situation awareness, reroute clearances, workload, and weather monitoring. This report describes the flight crew graphical weather interface, integration of the weather system with the flight navigation system, and data link transmission methods for sending weather data to the airplane.

Introduction

Acquiring and assimilating weather information while in flight is currently time consuming and labor intensive, especially in fast changing conditions associated with frontal activity and unstable weather regions. Voice communications with a company dispatcher, a company meteorologist, FAA ATC, FAA Weather Watch, or a Flight Service Station is the most common means for pilots to gather weather information. Printed textual weather information may be obtained on airplanes equipped with the appropriate ARINC Communications Addressing and Reporting Service (ACARS) data link system. When using these systems, the flight crew has to mentally assimilate multiple textual and verbal reports and forecasts into a mental picture of the weather conditions in the vicinity of the intended flight path.

Graphical presentation of weather information may help in making reroute decisions. In airline operations, reroute decisions are typically made by both the company dispatcher and flight crew. Having identical graphical weather displays for the company dispatcher and crew could enhance dialogue capabilities for reroute decisions and weather monitoring.

The data link system envisioned to support this graphical weather system utilizes a one way broadcast data link for surface observations, terminal forecasts, radar summaries, and lightning strike data. Computing facilities on board the airplane then construct graphical displays, moving weather displays, color textual displays, and other tools to

assist the crew with weather related decisions. The weather data is continually received and stored by the airborne system, giving the flight crew instantaneous access to the latest information. This information is color coded to distinguish degrees of category for surface observations, ceiling and visibilities, and ground radar summaries.

Limited automatic weather monitoring and crew alerting is accomplished by the airborne computing facilities. When a new surface or special observation for the intended destination or alternate is received by the airplane, the crew is informed so that the weather information can be studied at the pilot's discretion.

The graphical weather system display is shown on a multi-color eight inch cathode ray tube (CRT) with a touch panel overlaid. This CRT and touch panel implementation is also used for normal data link message exchange as described in references 1 and 2. Touch sensitive buttons and areas on the CRT formats are used for pilot selection of graphical and data link displays. Time critical ATC messages are presented in a small window that overlays other displays so that immediate pilot alerting and action can be taken.

This report will describe the display formats and functional operation.

Definitions

ACARS	ARINC Communications Reporting and Addressing System
ADS	Automatic dependent surveillance
AM1	Amendment 1
ARINC	Aeronautical Radio Incorporated
ARPT	Airport
ATC	Air traffic control
ATIS	Automatic Terminal Information Service
bps	Bits per second
BKN	Broken
BRKS	Breaks
C	Ceiling
CAT	Category
CDU	Control display unit
CH	Chance
CRT	Cathode ray tube
E	East
F	Fog
FAA	Federal Aviation Agency
FL	Flight level
FMS	Flight management system
H	Haze or flight hazard
hr	Hour
IFR	Instrument flight rules

LIFR	Low instrument flight rules
MCP	Mode control panel
MIA	Miami International Airport
min	Minute
MSG	Message
NC	North central
NE	North east
MVFR	Marginal visual flight rules
nm	Nautical mile
NW	North west
OC	Occasional
OVC	Overcast
P	Precipitation
R	Rain
R-	Light Rain
R-F	Light Rain and Fog
RF	Rain and Fog
RFD	Rear flight deck
RVR	Runway visibility range
SA	Surface observation
SC	South central
SE	South east
sec	Second
SCT	Scattered
SW	South west
TSRV	Transport Systems Research Vehicle
US	Contiguous United States
V	Visibility
VFR	Visual flight rules
VT	Valid time
WCP	Weather communications processor
WX	Weather
X	Sky obscured
Z	Zulu (Greenwich Mean Time)

Test Airplane Flight Deck

The graphical weather system was designed for implementation in the NASA Transport Systems Research Vehicle (TSRV) B-737 airplane research flight deck (RFD). The RFD, shown in figure 1, is a full size flight deck that contains eight 8" x 8" sized, flight quality, color CRT displays. Each pilot has a primary flight display, a navigation display, and a control display unit (CDU) to interface with the flight management system (FMS). The four CRT displays shown in the center panel of the cockpit are used for engine instruments, check lists, and for research test purposes. One of the lower center panel CRT's will be used for the graphical weather/data link interface with the crew. The crew has the ability to switch the display to either of the lower center CRT's.

Data Link Requirements

This system is designed to allow the crew instantaneous access to the graphical weather information. This is achieved by continuously receiving and storing weather information on board the airplane. In this design, weather information is sent continuously through a broadcast data link.

Figure 2 illustrates a satellite system used to broadcast data to all airplanes in the satellite coverage area. A broadcast-type system is proposed since receive only aircraft satellite equipment is simpler and less expensive than the current generation two way satellite transceivers. The Graphical Weather Processor (GWP) receives reports and forecasts from multiple sources. The GWP formats weather data into packets, and that weather information is then transmitted to all airplanes within the satellite coverage area. Data to be transmitted includes lightning ground strike information, national radar summaries, textual weather, and other weather reports entered by the ground operator.

National radar and lightning ground strike information is transmitted every fifteen minutes by the GWP. The airplane computer system places this information in a circular queue that stores the last six radar and lightning summaries.

Surface observations and terminal forecasts are transmitted by the GWP as soon as they are received. The airplane places this textual data in the "current" weather information buffer and is ready for display by the graphical weather system. At ten minutes past the hour, the current surface observations and terminal forecasts are copied into the history queue. The last five hours are saved for display by the graphical weather system.

Initialization of the graphical weather system is accomplished by preloading past weather information. A separate ground receiving system may be used to record weather information from the satellite and send that information to the airplane using a Gatelink connection (or floppy disks). This preloading of weather information will ensure that the airplane has all the current weather information when the onboard receiving equipment is activated.

Graphical Weather Display Formats

The airborne graphical weather system has been integrated with the existing data link communications interface (reference 1). Time-critical ATC messages received via data

link will overwrite weather graphics and other non-time critical displays.

Main Menu Page

The main menu page of the data link air/ground communications system is shown in figure 3. Activating the GRAPH WX button changes the display to the first map of the graphical weather system. A further description of the main menu page is given in reference 1.

The red cross hairs in figure 3 are used to draw the touch point as determined by the computer system. The cross hairs help overcome the parallax problems associated with mounting the touch panel in front of the surface of the CRT and with the crew viewing the display from either the left or right sides.

A stream touch mode is implemented so that the pilot can move his finger along the screen and the cross hairs will follow. When the computer determines that the touch point is on an active touch area such as a button or location identifier, the active area changes color and flashes. If the pilot removes his finger when over an active touch area, the computer considers the area to have been activated. This implementation was shown to work well in actual flight operations as discussed in reference 2.

Category Map Page

The Category Map, shown in figure 4, is the first map viewed when the GRAPH WX button is activated. This map displays the current categorical weather at airports throughout the map area. Each circular disk on the category map is color coded according to the categorical surface weather last reported at that location. Category is determined by the lower of ceiling and visibility as ranked in table 1. Thus an airport with a ceiling of 1500' and a visibility of 1/2nm would be graphed as LIFR category. This color coding gives the crew an awareness of the surface weather as reported in observations across the area covered by the map.

Integration of the graphical weather and flight management system facilitates the plotting of the active and provisional routes on the category map display. The active route is plotted in white and the provisional in yellow. This provides the crew a pictorial display of the surface observations along the active and provisional routes. The origin, destination, and alternate airports are also determined from the flight management system and plotted on the category map.

CATEGORY	COLOR	CEILING	VISIBILITY
VFR	LIGHT GREEN	$C \geq 3000'$	$V \geq 5nm$
MVFR	DARK GREEN	$3000' > C \geq 1000'$	$5nm > V \geq 3nm$
IFR	YELLOW	$1000' > C \geq 500'$	$3nm > V \geq 1nm$
LIFR	ORANGE	$500' > C \geq 200'$	$1nm > V \geq 2400' RVR$
CAT II	RED	$200' > C \geq 100'$	$2400' RVR > V \geq 1200' RVR$
CAT III	DARK RED	$100' > C$	$1200' RVR > V$

Table 1: Category and Color

Weather monitoring is enhanced by alerting the pilot crew when a new surface observation for the destination or alternate airport is received. This alerting is accomplished by flashing the perimeter of the color disk for that location. After the crew has viewed this new observation, the perimeter quits flashing.

Active touch areas on the Category Map display include the colored circular disks representing the airports, the color spectrum, and the buttons along the bottom. Activating a color disk draws up the Surface Observation and Terminal Forecast display (described later). The buttons and color spectrum along the bottom of the category map are common to all the weather maps and are discussed next.

Map Page Buttons and Color Spectrum

The buttons on the bottom of each map display are exactly the same. They are labeled MAP, HIST, SCALE, ARPT, and MAIN, as illustrated in figure 4.

MAP Button. Activating the MAP button changes the map display to the next map display contained in a circular queue of maps. The sequence of displays in the queue is the Category Map page, the Ceiling and Visibility Map page, the Radar Map page, and the Lightning Strike Map page. The crew can circulate amongst the map displays by repeatedly activating the MAP button.

HIST Button. Weather trend information is available by activating the history (HIST) button. When the HIST button is activated, the last five recordings of that particular map are displayed in sequential order. For example, if the Category Map page is displayed when the HIST button is activated, Category Map pages recorded for the last five hours are automatically played back so that the crew can see the historical change in the categorical

weather. This provides the crew with trend information for future weather changes.

SCALE Button. Activating the SCALE button on any of the map pages displays the Scale Selection Page as shown in figure 5. The letters represent various sections of the United States (US). Activating one of the touch sensitive letter identifiers, US, E, W, NW, SW, NC, SC, NE, or SE, causes the display to return to the previous map page displaying the chosen area. All map pages selected will be displayed at the last chosen scale until a new scale is chosen or the graphical weather system is exited. The US scale is used as the default scale each time the system is entered.

When the LOCAL touch area is activated, a green rectangular outline representing 3.5 deg of latitude and 4 deg of longitude is drawn. The crew may then drag the box by touch to the desired location, as shown in figure 6. When the touch is removed, the display shows the map page for that area.

ARPT Button. Activating the airport (ARPT) button replaces each colored disk with the three letter location identifier which tells the crew which airports are being graphed. The identifiers are also touch sensitive so that the crew can call up the surface observations and terminal forecast by activating the identifier. The ARPT button works slightly differently on the Radar Map and Lightning Map pages and will be discussed later in those sections.

Also when the ARPT button is activated, the CDU key pad and CDU scratch pad are seized so that the crew can type in the three letter identifier of any location in the data base. Activating the ARPT button again will then free the CDU and return the surface observations and terminal forecast for that location to the graphical weather display. This allows access to information about airports that are not being displayed on the map page.

Main Button. Activating the MAIN button returns the display to the Main Menu page (figure 3), of the data link communications system.

Color Spectrum. A six level color spectrum, shown on all map displays, was chosen for representation of radar echo intensity and weather category. This standard color spectrum is used by many color weather graphics providers.

The Color Key page, shown in figure 7, may be selected by activating the color spectrum on any of the display pages. The color coding for the Category Map page, the Ceiling and

Visibility Map page and the Radar Map page is presented on this Color Key page.

The category symbols on the Color Key are touch sensitive so that the pilot crew can activate any of the symbols to find the definition used for that category. When a category symbol is activated, a small window appears with a definition of that category. Definitions displayed are those shown in table 1.

The next section on the Ceiling and Visibility Map page will discuss the coding of the rectangles and the section on the Radar Map page will discuss radar echo intensity coloring.

Ceiling and Visibility Map Page

Activating the MAP button on the Category Map page changes the display to the Ceiling and Visibility Map page as illustrated in figure 8. Each report is represented by a square. The square is divided into an upper rectangle color coded for the ceiling category and a lower rectangle color coded for visibility category. The crew can then discern visibilities and ceilings from this display. The color code is shown in table 1. For example, if the upper rectangle of a square is light green and the lower rectangle of the same square is yellow, the surface observation reported for that airport would have a VFR ceiling of greater than or equal to 3000' and an IFR visibility of less than 3 nm and greater than, or equal to, 1 nm.

Other information displayed on the Ceiling and Visibility Map include winds > 30 knots, precipitation, and reported flight hazards. When winds are reported to be greater than 30 knots, the horizontal bar separating the upper and lower rectangles of the square disk is flashed in white. A "P" is drawn next to each square when precipitation is reported at that airport. When a flight hazard such as freezing rain, a thunderstorm, or a tornado is reported, a red flashing "H" is shown beside that location. The pilot may touch any of the squares to display the surface observations and terminal forecast for that location to find more information.

Radar Summary Map Page

Ground-based radar summaries are constructed every 15 minutes and transmitted to the aircraft graphical weather system. Color coding represents six levels of radar reflectivity corresponding to the Video Integrator Processor levels used in reference 3. These color codings may be viewed on the Color Key page (figure 7) by the crew.

The Radar Summary Map page is accessed by activating the MAP button of the ceiling and visibility map page. The Radar Summary Map page (figure 9), displays the ground-based radar summary, time stamped in the lower right hand corner of the display with the time of reception. Each pixel size is 8km by 8km (4.32nm by 4.32nm). This radar display is not intended to be used for tactical decisions or to replace the airborne weather radar. It is intended to give "big picture" weather information for longer range strategic planning and weather monitoring.

Activating the ARPT button on the Radar Summary Map page will overlay three letter airport identifiers on the radar summary. These are the same airports displayed on the Category Map Page. The crew can then obtain the surface observations and terminal forecast for a location by activating a three letter identifier or by typing in a three letter identifier in the CDU. Displaying the three letter identifiers on the radar summary gives the crew awareness of the location of radar echoes relative to airports.

Lightning Ground Strike Map Page

Ground-based lightning strike summaries are constructed every 15 minutes. Each summary contains five minutes of lightning ground strike data including the location and polarity of each strike. This data is recorded by the GWP and transmitted to the airplane.

The Lightning Ground Strike Map page (figure 10), graphs each positive strike with a "+" and each negative strike with a "-". Since the typical life of a thunderstorm is between 20 minutes and 1 1/2 hours (reference 4), a sample every fifteen minutes can detect typical thunderstorm cells.

The ARPT button works exactly the same as on the Radar Summary Map page as described above.

Surface Observation and Terminal Forecast Page

The Surface Observation and Terminal Forecast Page (figure 11) shows the last five surface observations in the top half of the page and the terminal forecast in the bottom half. This page may be accessed by activating one of the disks or three letter identifiers on the Category or Ceiling and Visibility map pages, or by using the CDU as previously discussed.

On the top of this page, the last surface observation is displayed both in coded form in the top two lines and in a decoded form on line three. The next four oldest reports are also displayed in decoded form. The decoded

observations are color coded according to category, arranged in chronological order, and displayed with the time of observation, cloud information, visibility, temperature, dew point, wind, and altimeter setting.

Data Link Message Integration

The graphical weather system is integrated into the TSRV data link communications system sharing the same CRT and touch panel, and common access to other airplane systems. The MAIN button allows access to the data link communications system from the graphical weather system and the GRAPH WX button provides access to the graphical weather system. Time critical and non-time critical ground-to-air data link messages, as defined in reference 1, are treated differently when the graphical weather system is being used by the crew.

When a non-time critical message is received by the airplane and the graphical weather is being accessed, annunciations are presented to the pilot. "DL MSG" is flashed above the color spectrum on the graphical weather display, on the primary flight display, and on the navigation display. The crew may display the message by touching and releasing the DL MSG symbol on the graphical weather display.

Time critical messages, including tactical and route clearances received from ATC, are immediately spoken by a computer voice and displayed to the crew in a small window overwriting the graphical weather or data link display as shown in figure 12.

When a route clearance is received by the airplane, the scratch pad of the CDU is stored in memory and the route is inserted in the flight management system as the provisional path and displayed on the navigation display. Also, on the graphical weather display (or data link display), a GRAPH WX button appears, see figure 12. Activating the GRAPH WX button removes the small window from the display so that the pilot crew can view the path clearance in relation to the weather. The MAIN button is replaced with a MSG PNDG button which returns the small window for pilot action.

When a tactical message arrives, it is spoken by the computer voice system and displayed in a small window overwriting the graphical weather/data link display. Tactical messages must be rogered or unabled before any other action.

CONCLUDING REMARKS

The graphical weather system presented in this memorandum was designed for the NASA Transport Systems Research Vehicle B-737. This system will be used in simulation experiments evaluating cockpit weather information needs, and may be changed at any time. A future report will describe the graphical weather system to be implemented for flight testing.

REFERENCES

1. Knox, C. E. and Scanlon, C. H., "NASA Transport Systems Research Vehicle B-737 Data Link Display Formats", NASA TM 102717, August 1990.
2. Knox, C. E. and Scanlon, C. H., "Flight Tests With a Data Link Used for Air Traffic Control Information Exchange", NASA TP 3135, September 1991.
3. "Aviation Weather Services", U.S. Government Printing Office, Advisory Circular 00-45C.
4. "Aviation Weather", U.S. Government Printing Office, Advisory Circular 00-6A.

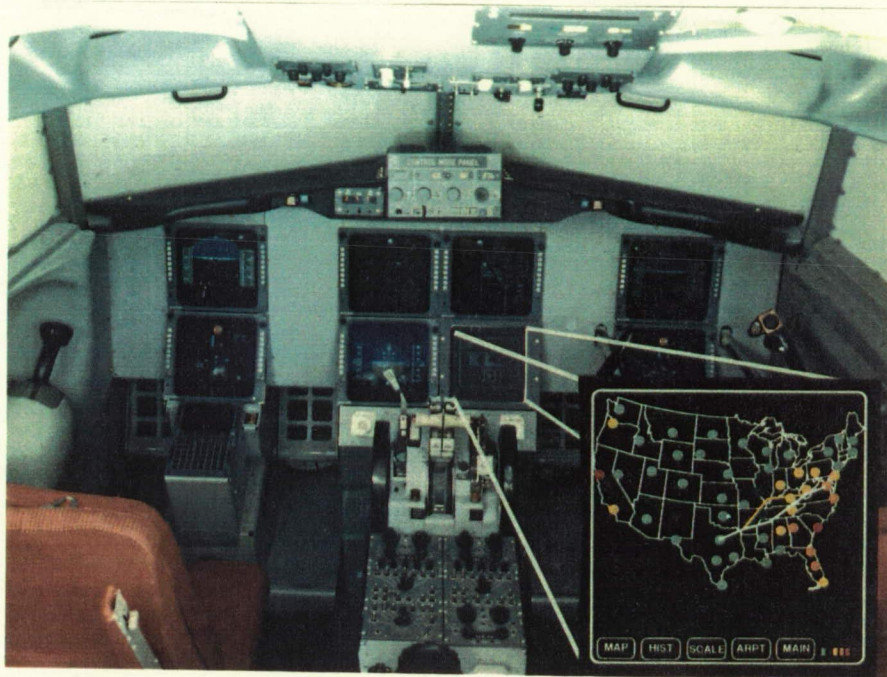


Figure 1: The Aft Flight Deck and Simulator Graphical Weather Location.

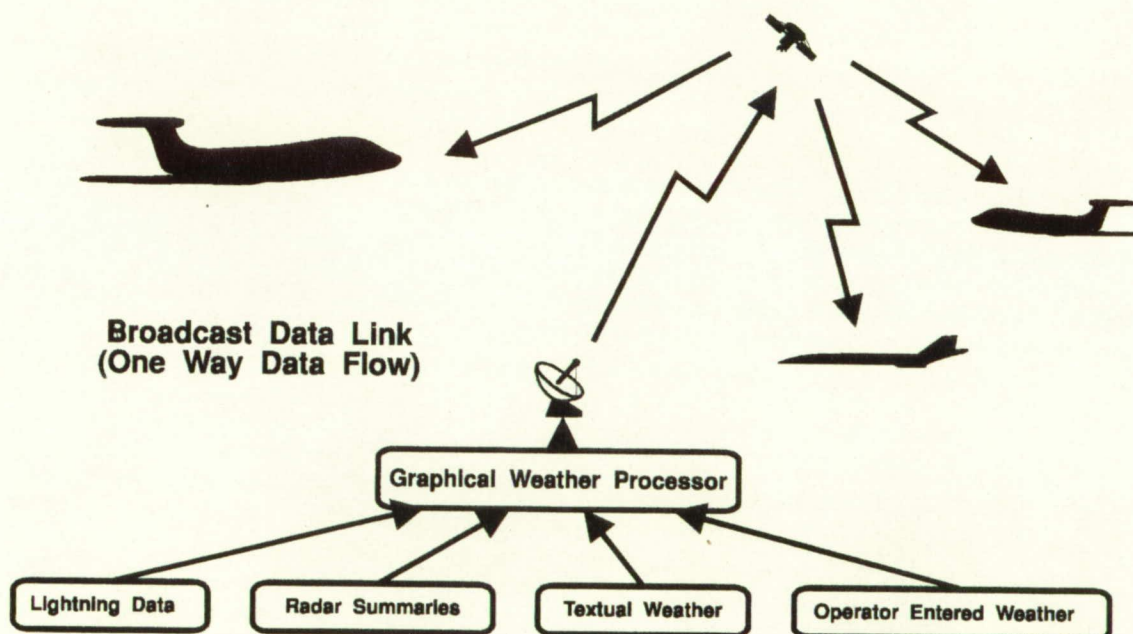


Figure 2: Graphical Weather Data Flow.

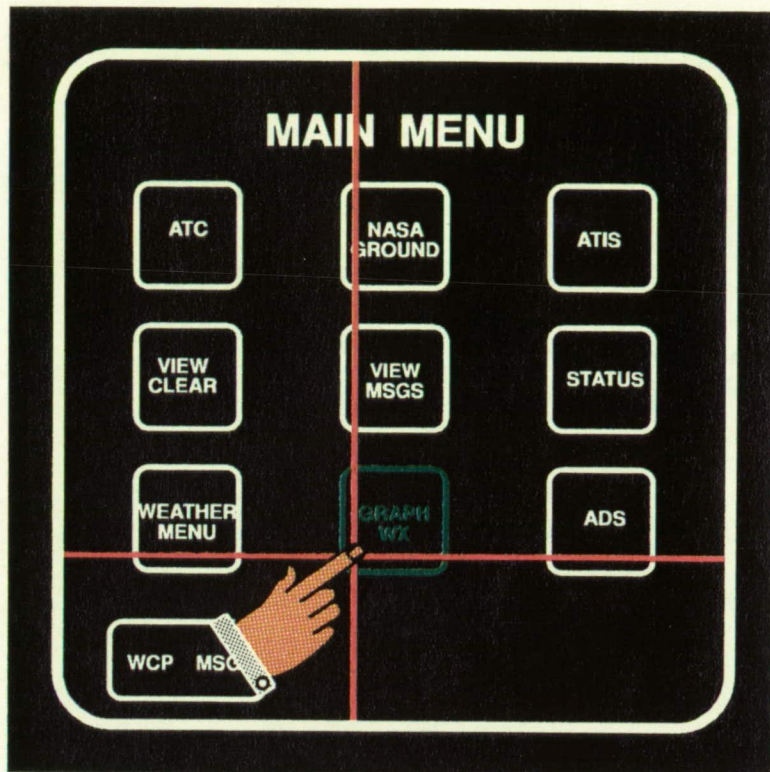


Figure 3: Main Data Link Menu.

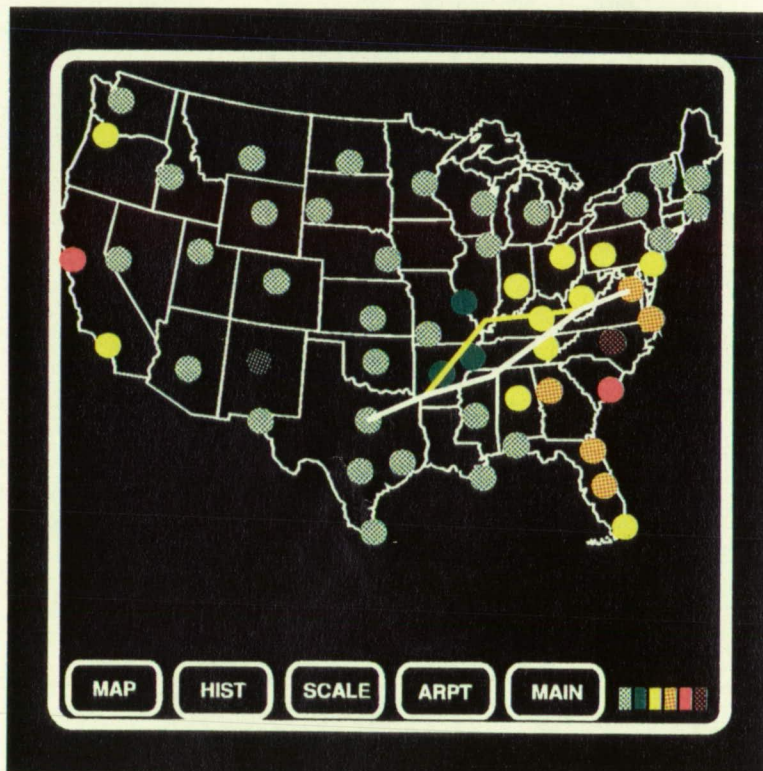


Figure 4: Category Map.



Figure 5: Scale Selection.



Figure 6: Local Scale Selection.

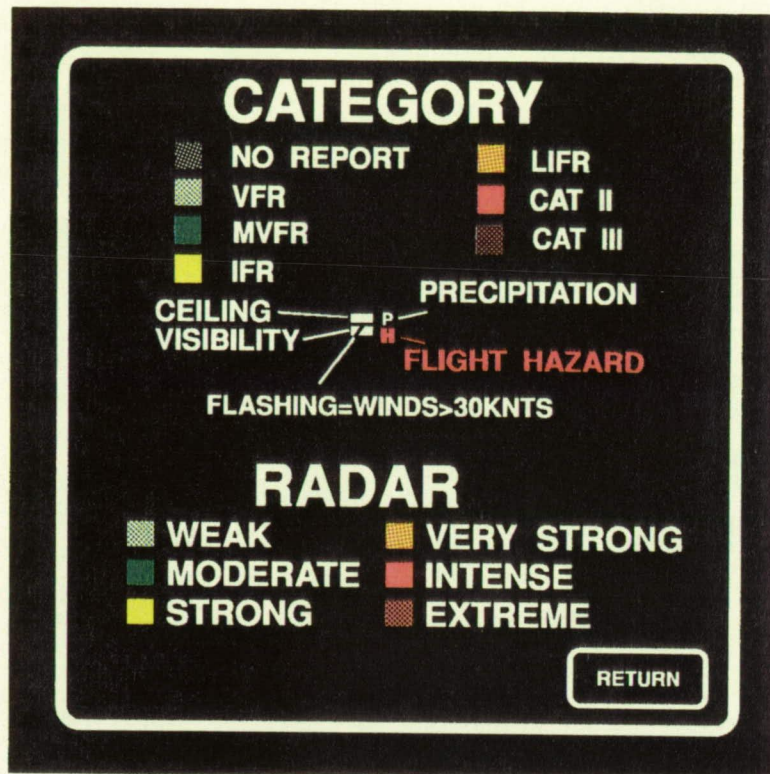


Figure 7: Color Key



Figure 8: Ceiling and Visibility Map.

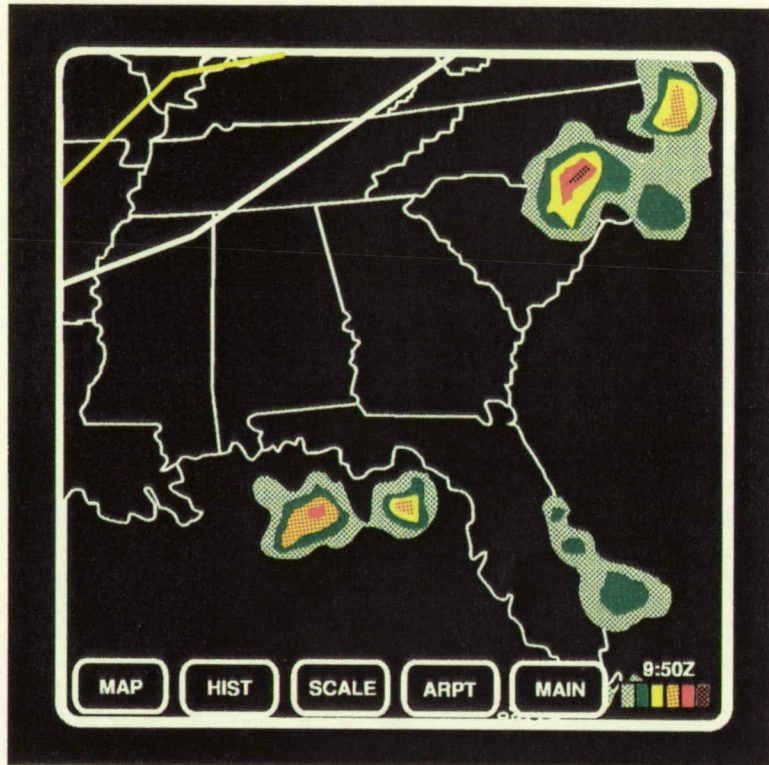


Figure 9: Radar Summary Map.

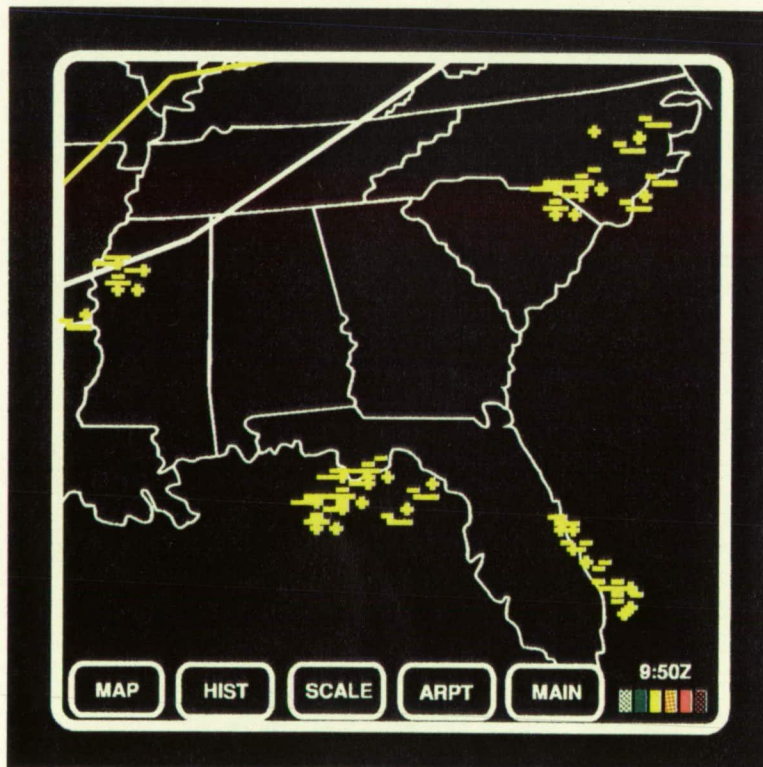


Figure 10: Lightning Strike Map.

ORIGINAL PAGE
COLOR PHOTOGRAPH

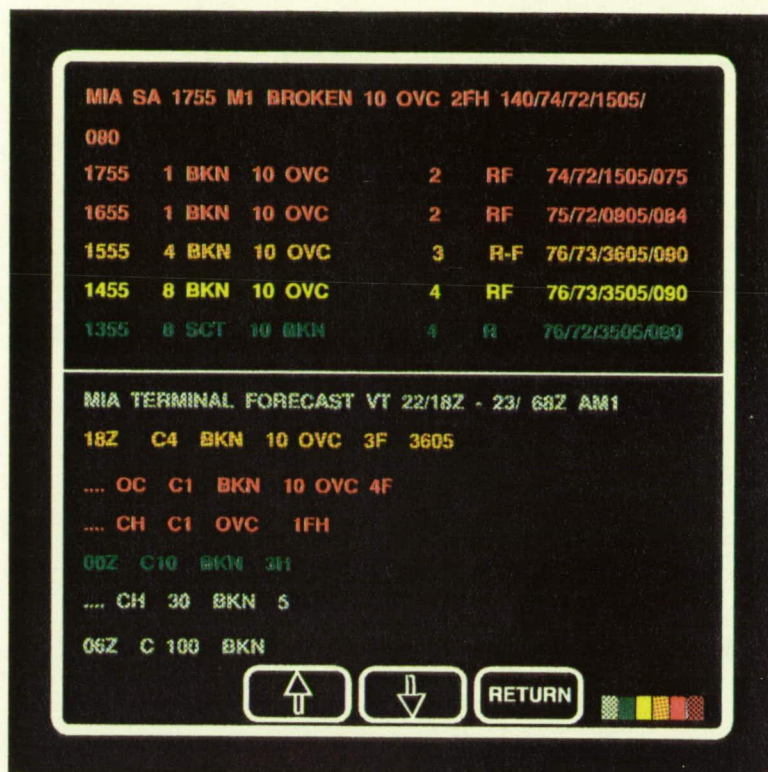


Figure 11: Surface Observation and Terminal Forecast Display.



Figure 12: Category Map with a Route Clearance.

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COCKPIT WEATHER INFORMATION NEEDS (CWIN)

Charles H. Scanlon
Vehicle Operations Research Branch
NASA Langley Research Center
November 30, 1993

Problems Addressed

Pilots Have Difficulty

- Obtaining A Large Volume Of Weather Information.
- Assimilating Weather Information.
- Obtaining Timely Weather Information.
- Evaluating Routes For Weather Avoidance.
- Developing Trend Information

Resulting In

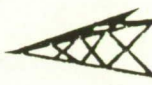
- Incomplete Weather Situation Awareness.
- Problems Monitoring Weather.
- Difficulty Making Strategic Reroute Decisions.

21st Century Aviation Weather Data Flow

Broadcast Satellite



Request-Reply Satellite



"Big Picture"
Weather Information

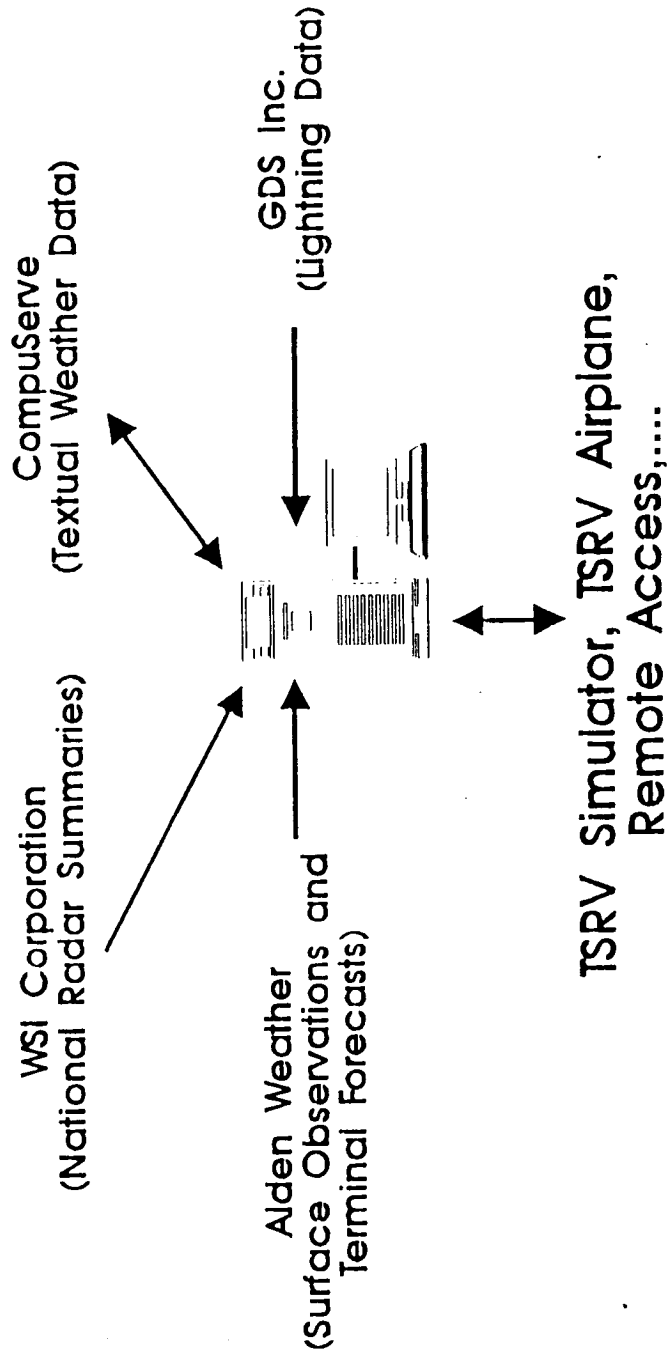
Local and Route Specific
Weather Information

Mode-S, VHF, UHF, ...
Two Way and Broadcast



CWIN Pilot Interface

Live Weather Connections



Note: Live weather was only used for demonstration. Recorded/alterred weather was used during data collection.

Simulation Test Pilot Advisory Panel

Captain Dave Simmon, Lockheed Engineering

Captain Robert Sumwalt, III, US Air

Tim Miner, American Airlines

Gary Lohr, Embry-Riddle Aeronautical University

Lee Person, NASA Langley Research Center

SIMULATION TEST OUTLINE

- Fourteen Airline Transport Pilot Crews Representing USAir, United, Northwest, America West, Boeing, and Honeywell.
- Each Crew Flew Four Full Flight Scenarios (Two Denver to Reno, and Two Denver to St Louis).
- Each Crew Flew Two Flights With The CWIN System and Two Without The CWIN System.
- Each En Route Segment Required A Deviation Around Convective Activity.
- Two Scenarios Had The Airport Close When The Airplane Was On Close Final.
- Retired Controllers Used For ATC and Dispatch.

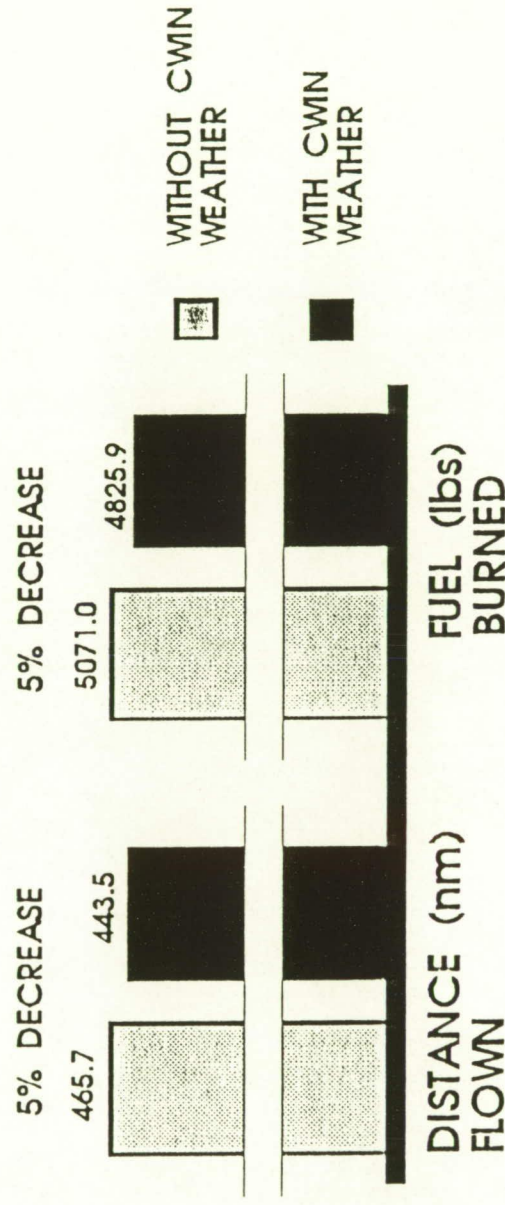
RECORDED DATA INCLUDED

- VIDEO AND AUDIO OF THE COCKPIT
- REAL TIME VARIABLES (SPEED, ATTITUDE, DISPLAYS, POSITION,....)
- PRETEST QUESTIONNAIRE
- PHYSIOLOGICAL MEASURES (HEART RATE, SWEAT,....)
- COMMUNICATIONS (DATA LINK AND VOICE WITH ATC AND DISPATCH)
- RESEARCHER NOTES
- PILOT COMMENTS
- NASA TASK LOAD INDEX (SUBJECTIVE WORKLOAD)
- POSTTEST QUESTIONNAIRE
- WEATHER SITUATION AWARENESS QUESTIONS DURING SCENARIO 3

SOME PRELIMINARY TEST RESULTS

IMPROVED ENROUTE EFFICIENCY

- ENROUTE DISTANCE AND FUEL SAVED:



- AIRLINE PILOTS DEViate AROUND ADVERSE WEATHER ENROUTE ON THE AVERAGE OF 1 IN 12.8 FLIGHTS.
- THUS, A $5\% \times 1/12.8 = .4\%$ SAVINGS OF ENROUTE OPERATING COSTS FOR ALL FLIGHTS IS INDICATED BY THIS TEST.

HOW MUCH WOULD THE .4% ENROUTE SAVINGS INDICATED BY THIS STUDY SAVE AN AIRLINE? (BALL PARK FIGURES)

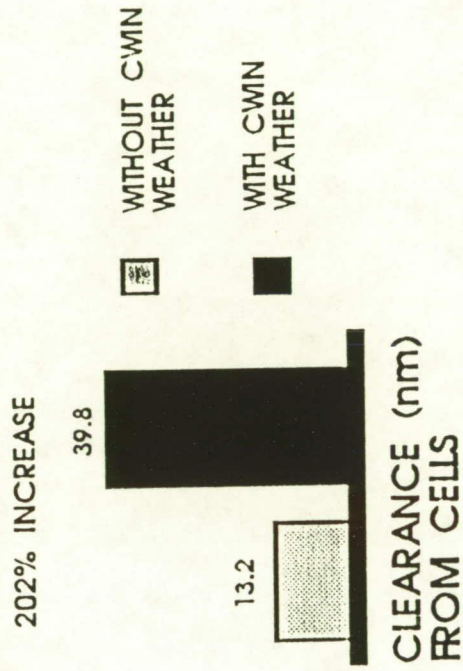
ASSUMPTIONS ABOUT DOMESTIC FLIGHT OPERATIONS FOR AIRLINE X:

HAS 350 AIRPLANES
\$1200/HR/AIRPLANE OPERATING COSTS
12HRS/DAY UTILIZATION
2 HR FLIGHTS ON AVERAGE
80% ENROUTE

ANSWER: SAVINGS = $350 * 1200 * 12 * 365 * .8 * .004$ = **\$5.9M/YR**

ENHANCED SAFETY

- DISTANCE OR CLEARANCE FROM THUNDERSTORMS WHILE ENROUTE WAS LARGER



- PILOT QUESTIONNAIRE RESPONSE: "SAFETY OF FLIGHT DURING ADVERSE WEATHER OPERATIONS"

**CURRENT SYSTEM
MUCH BETTER**

**CWIN SYSTEM
MUCH BETTER**

			1	2	5	18
--	--	--	---	---	---	----

BETTER SITUATION AWARENESS

- WITH THE CWIN GRAPHICAL WEATHER PRESENTATION, SITUATION AWARENESS WAS

CURRENT SYSTEM MUCH BETTER					1	4	CWIN SYSTEM MUCH BETTER
							20

- YOUR ABILITY TO MONITOR WEATHER ALONG YOUR FLIGHT PATH

[illegible]

- DURING THE “FREEZE” OF SCENARIO 3, CREWS USING THE CWIN SYSTEM WERE MUCH MORE AWARE OF WEATHER ALONG THE ROUTE THAN THOSE CREWS NOT USING THE CWIN SYSTEM.

PILOT RESPONSE TO UTILITY OF SOME CWIN FEATURES:

The Lightning Map:

OF NO USE ESSENTIAL

					1	4	19
--	--	--	--	--	---	---	----

The National Radar Map:

OF NO USE ESSENTIAL

					1	4	20
--	--	--	--	--	---	---	----

The History Button:

OF NO USE ESSENTIAL

						2	3	20
--	--	--	--	--	--	---	---	----

The Scale Selection:

OF NO USE ESSENTIAL

							1	6	18
--	--	--	--	--	--	--	---	---	----

THIS TEST SHOWS NEED FOR ADVANCED COCKPIT WEATHER PRODUCTS INCLUDING:

- **RADAR COMPOSITE MAPS WITH HISTORY
FEATURE**
- **LIGHTNING MAPS WITH HISTORY FEATURE**
- **GRAPHICAL REPRESENTATION OF SURFACE
OBSERVATIONS**

FUTURE CWIN RESEARCH

- **A FLIGHT TEST IN THE NASA TSVR AIRPLANE VALIDATING SIMULATION TEST RESULTS AND DEMONSTRATING A SATELLITE BROADCAST DATA LINK.**
- **SIMULATION AND FLIGHT TESTS ADDRESSING COCKPIT WEATHER INFORMATION NEEDS FOR OCEANIC FLIGHT OPERATIONS.**